# Land Border Monitoring with remote sensing technologies

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## ABSTRACT

The remote sensing technology has many practical applications in different fields of science and industry. There is also a need to examine its usefulness for the purpose of land border surveillance. This research started with analysis of potential direct use of Earth Observation technology for monitoring migrations of people and preventing smuggling. The research, however, proved that there are still many fields within which the EO technology needs to be improved. From that point the analysis focused on improving Border Permeability Index which utilizes EO techniques as a source of information. The result of BPI analysis with use of high resolution data provides new kind of information which can support and make more effective work of authorities from security domain.

**Keywords:** GIS, land monitoring, migrations, remote sensing, spatial analysis, spatial modelling

## 1. INTRODUCTION

The Land Border Monitoring activity (LBM) is one of many thematic areas that constitute the LIMES project (*Land and Sea Integrated Monitoring for European Security*). The project is co-founded by the European Commission within the 6$^{th}$ Framework Programme as one of the projects that are related to the security domain of GMES program (Global Monitoring for Environment and Security). The main aim of that project was to do research and develop applications and services that intend to utilise the Earth Observations (EO) technology to increase the security in Europe.

As its name indicates LIMES LBM insists on monitoring the external land borders of EU. The activities of the LBM cluster concerns research on possibilities of using the remote sensing technologies (RS) to support work of the LBM End Users to which belong the authorities whose activities is directly related to the security domain of border monitoring (e.g. Border Guards of EU countries, Frontex Agency).

The main areas of LBM users' interests and so directly areas in which RS technology is supposed to be implemented are immigration (legal and illegal), smuggling of goods and people and military threats. A preliminary research revealed that the mentioned areas of interest cannot be directly supported with the use of the EO technology. The encountered limitations are related to the impossibility of permanent (24h/day) monitoring of border areas by satellite sensors. It is also impossible to penetrate tree canopy (forested areas) by satellite sensors in order to find people or vehicles underneath or recognise different types of vehicles (also in forested area).

However, the research and work conducted within the project allowed to develop services that consist of cartographic products and are intended to support the work of authorities in the security domain by providing additional information

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necessary for their daily activities and in an emergency. During the work on services several different processing steps were applied. These include both remote sensing processes (e.g. orthorectification, classification of satellite optical and radar imagery) and spatial modelling and analyses.

One of the products developed in the project is the Border Permeability Index Map. The Border Permeability Index Map is a cartographic product which presents the classification of border areas according to the easiness of crossing it for illegal immigrants. The concept of Border Permeability Index (BPI) was widely explored by researchers from Institute for the Protection and Security of the Citizen of Joint Research Centre (JRC) and researchers from Centro di Ricerca Progetto San Marco (GMOSS Project, CRPSM).

According to the research done by JRC the BPI model 'is focused on the geographic permeability related to a standard adult person having illegal behaviour and deciding to cross the green border by foot' (Stephenne, et al. 2007).

The mentioned research was conducted at the continental level and analysed the area along the border from the Norwegian – Russian border in the north to the Greek borders with non-EU countries in the south of Europe. It was based on spatial analysis on over 20 spatial datasets with fuzzy multi - criteria evaluation methodology with spatial resolution of 1 kilometre.

The researchers from CRPSM worked on the area of the borders between six countries (Kenya, Uganda, Tanzania, Rwanda, Burundi and the Democratic Republic of Congo). Their analysis was based on three different datasets and use of Boolen approach for permeability calculation.

The mentioned research is the most comprehensive work on given subject and because of that it constitutes the best source of information and the starting point for other works.

The research described in this paper in some part is based on methodology worked out in the JRC approach. However, the main aim here was to adjust and evaluate the methodology for much smaller area and to try increase the precision and accuracy to provide results relevant to the scale of work.

## 2. DATASETS

The research was conducted for the area of 20 km on both sides of the Polish – Ukrainian border (Figure 1) that is an area of about 13500 km$^2$. This area contains together urban, arable and forested areas and covers both flat and mountainous terrain. The examined area is very important as a part of external border of the EU and as an area of intensified movement of people during forthcoming European Football Championship (2012).


Figure 1. The study area of the research (marked by red line).

During the analysis several different datasets layers were utilized to produce the final result.

One of the most important sources of information for BPI analysis is land cover information which in this case was acquired from two sources. The first was the Corine Land Cover dataset (CLC2006) and this was available for the Polish side of the border. This dataset comes from year 2006 and provide information about land cover with division into 44 classes and is made at scale of 1:100 000. The idea to utilize the CLC2006 data comes from the fact that it is available for all EU countries and because of that it can be easily applied for other areas.

For the Ukrainian side where the CLC2006 dataset is not available it was necessary to use different data. For that purpose the IMAGE2006 dataset was use which is a collection of imagery from SPOT4, SPOT5 and IRS satellites acquired between 2005 and 2007. For the area of Polish – Ukrainian border only images from IRS – P6 sensor were available with spatial resolution of about 23 meters.

The next data used in the research is ASTER Global Digital Elevation Model (GDEM) produced by METI (Ministry of Economy, Trade and Industry, JAPAN) and NASA(The National Aeronautics and Space Administration, USA). The data provided by NASA webpage is stored with spatial resolution of 30 meters and presents accuracies of 20 m at 95 % confidence for vertical data and 30 m at 95 % confidence for horizontal data (ASTER GDEM, 2009).

Information about infrastructure network came from two datasets that was VMap Level 2 and ESRI Data & Maps datasets. Both data packages are in vector format and provides information at scale 1: 50 000. The VMap data provided information about road network (major roads, forest roads and lanes) and information about railroads network comes from ESRI datasets.

The last set of data is the Ambient temperature in Europe provided by Institute of Energy at JRC (**Huld, et al 2006**). This data presents information about the average ambient temperature in Europe in different months with spatial resolution of 1 km x 1 km. For the analysis the necessary data comes from months January and July.

## 3. METODOLOGY

The workflow of the analysis can be divided into two steps. The first step was the preparation of land cover data and the second the process of data synchronization and modelling.

### 3.1 Land cover data

For the purpose of BPI analysis the CLC classification was too much detailed (the number of specified classes) and the dataset was reclassified into 6 classes in order to reduce the redundant data. The necessary classes are: High vegetation area (forest), Low vegetation area, Open area, Populated area, Waters and Wetlands.

Because of the lack of CLC data on Ukrainian side it was necessary to utilise IMAGE2006 data. For that reason the IRS imagery was classified based on object – oriented approach according to classes from CLC2006 data and then reclassified into 6 classes mentioned previously. Finally the two datasets were merged to produce one common layer.

### 3.2 Data modelling

The process of data modelling was partially based on JRC analysis. However, comparing to the previous research there were only two criteria evaluated in this work, the ‘walk’ and ‘hide’ criteria. The original ‘secure’ criterion was not taken into account here because of lack of reliable data that could provide information about border guards’ units location and patrolled areas – information necessary to create ‘secure’ criterion.

The analysis was carried out in ArcGIS Desktop software of ESRI using available tools and Model Builder application for creating models ready to be used repetitively.

All parameters in the research were adjusted to the main assumption which states that the achieved result should be combatable with the capacity and physical fitness of average adult person to cross the border zones.

At the beginning every data layers were projected to common coordinate reference system appropriate for the study area – Universal Transverse Mercator Zone 34N.

At the next step all data was converted to the raster format to enable to use spatial analysis functions.

To make it possible to analyse different source of information and combine them together all data were standardised to common values scale. The same method of classification for Walk and Hide criteria was necessary to enable to compare them at the final stage of analysis. The standardization of data was achieved by creation of five classes according to which all information layers were classified. In both criteria the class 1 expresses the best possibility and class 5 the worst possibility for intruder to succeed in crossing border zone.

### 3.2.1 Walk criterion

The Walk criterion calculation is related to the analysis of terrain characteristics and classification of terrain regarding to the easiness of walking. The analysis takes into account different types of data and examines the influence it has on the easiness and speed of walking.

The parameters that were specified for the purpose of modelling of Walk criterion are related to the following features:

- land cover - information about land cover was crucial for the analysis because the specific land cover type is one of the parameters that has the biggest influence on the speed of walking and in a high degree determines how easily and fast a hypothetical intruder (illegal immigrant) can cross an area within the border zone. Depending on the type of land cover the intruder can make a decision about the direction of its travel preferring rather to avoid terrain which can require to make much more effort or spend more time to pass a specific distance. Taking this into account it is easier to cross open areas then the ones densely forested. Similarly areas covered by water (lakes and rivers) can constitute a real obstacle and very often can be treated as a complete barrier.

  Considering the above mentioned assumptions the water should be treated as the most problematic land cover class for walking person, followed by wetland and high and low vegetation areas. The open and populated areas were considered as less demanding classes.

- elevation – the altitude of terrain has an inverse influence on easiness of walking. The basic assumption states that the higher the altitude the more difficult the terrain becomes. As a point from which the altitude starts to influence the act of walking negatively was the elevation of 1000 meters. From that point the difficulty in moving on foot grows gradually until the altitude of about 2000 meters from which it is treated as extremely difficult.

- slope of terrain – similarly to the aspect of elevation, the slope of terrain makes it more difficult to walk as its percentage increases. Walking is not affected by the slope of terrain until its value of 20 % and becomes more difficult with growth of its value until 40 %. After that level walking in a mountainous area is seen to be almost impossible.

- Infrastructure – within the analysis which measures the easiness of moving it is necessary to take into account the infrastructure network which represents some kind of corridors for easier relocation not only for vehicles but also for walking people. A different scale of infrastructure network density makes given area more or less accessible. In the presented research both the road and railroad network were considered to be very easy to be crossed for potential intruder.

Another very prominent factor in the analysis of Walk criterion which determines the easiness of walking is weather conditions. The most important in that case are information about snow cover and temperature. Because of lack of snow cover information this factor was not taken into account in the research. Ambient temperature was the only weather factor examined here.

The basic assumption states that the lower the temperature (especially below 0° of Celsius) the more difficult it is to walk. However even more important here was the fact that in temperature below 0° of Celsius the water bodies freeze and after a series of days with such a condition it becomes possible for walking person to cross the water bodies on foot. This has been stated to be possible for months for which the mean temperature is below 0°. According to information about mean temperature in January the whole study area meets this condition and in such case the water bodies become more suitable for crossing them on foot.

### 3.2.2 Hide criterion

The Hide criterion of the BPI analysis is a classification of terrain according to the possibility of staying hidden. The hypothetical intruder during his way across the border area has to move quickly but also needs to stay not seen by both the border guard officers and civilians to avoid being stopped.

In that case two datasets were examined to create the Hide criterion map.

- land cover – similarly as in Walk criterion the land cover information constitutes the most important layer. Some classes have the same meaning and present some kind of obstacle or barrier. It was impossible to cross water bodies and also they are areas within which it is very difficult for intruder to stay unseen. The populated areas have inverse use and in that case are seen to be rather difficult areas to hide mainly because of its dense population. The high and low vegetation terrains seem to be perfect for the purpose of relocation without being seen and arrested.
- slope of terrain - the slope of terrain in opposition to the Walk criterion assumption acts here inversely. The lower the percentage of slope (theoretically plain terrain) the bigger possibilities for being observed by other people. The threshold values stay the same as in the case of Walk criterion (20 and 40 %) but their meanings are opposite.

#### 3.2.3 Combination of Walk and Hide criteria

It the final step of the BPI analysis the two previously described criteria was combined into one layer. This process was made by comparison of values for each pixel in the same locations on both Walk and Hide maps. The result provided 20 different combinations of five input values from two datasets. Then it was necessary to group the new received values and this process was done manually providing new classes which finally became the classes of permeability of the border area. This process required to think in the way the potential intruder does and choose which criterion is more important – Walk or Hide and decide from which criterion the value has greater importance.

## 4. RESULT

The process of classification of IRS imagery allowed together with CLC2006 data to create ready to use land cover information layer. The final result of classification provided the overall accuracy of about 85% and division of land cover into six predefined classes necessary for BPI calculation (Figure 2).

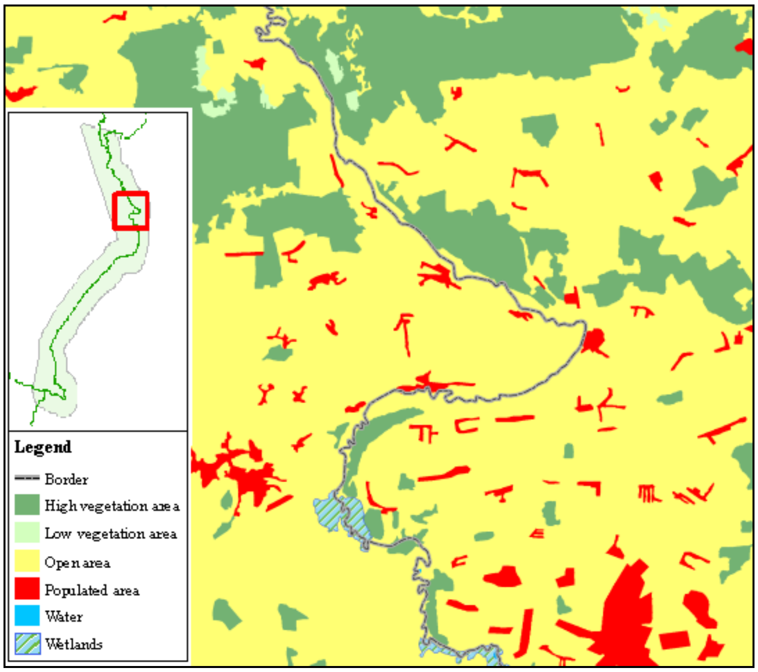


Figure 2. The result of IRS imagery classification.

The Geographic Information System (GIS) provides possibilities for carrying out spatial analyses using many different sources of information. Thanks to that it was possible to combine information about land cover, elevation and slope of terrain, infrastructure and weather condition.

The analyses of each criterion produced thematic layers that can be interpreted separately but also make up input layers for other research as the BPI analysis. The proper interpretation of received information can support work of intelligence and provide additional material for analysis of immigration aspect.

All three output layers can be seen in Figure 3 as a cartographic product. The Walk and Hide map has the same legend with five classes of easiness of walking and staying hidden. The BPI map is also represented by five classes which express the level of permeability of the border zone (Very permeable, Permeable, Moderately permeable, Hardly permeable and Not permeable).

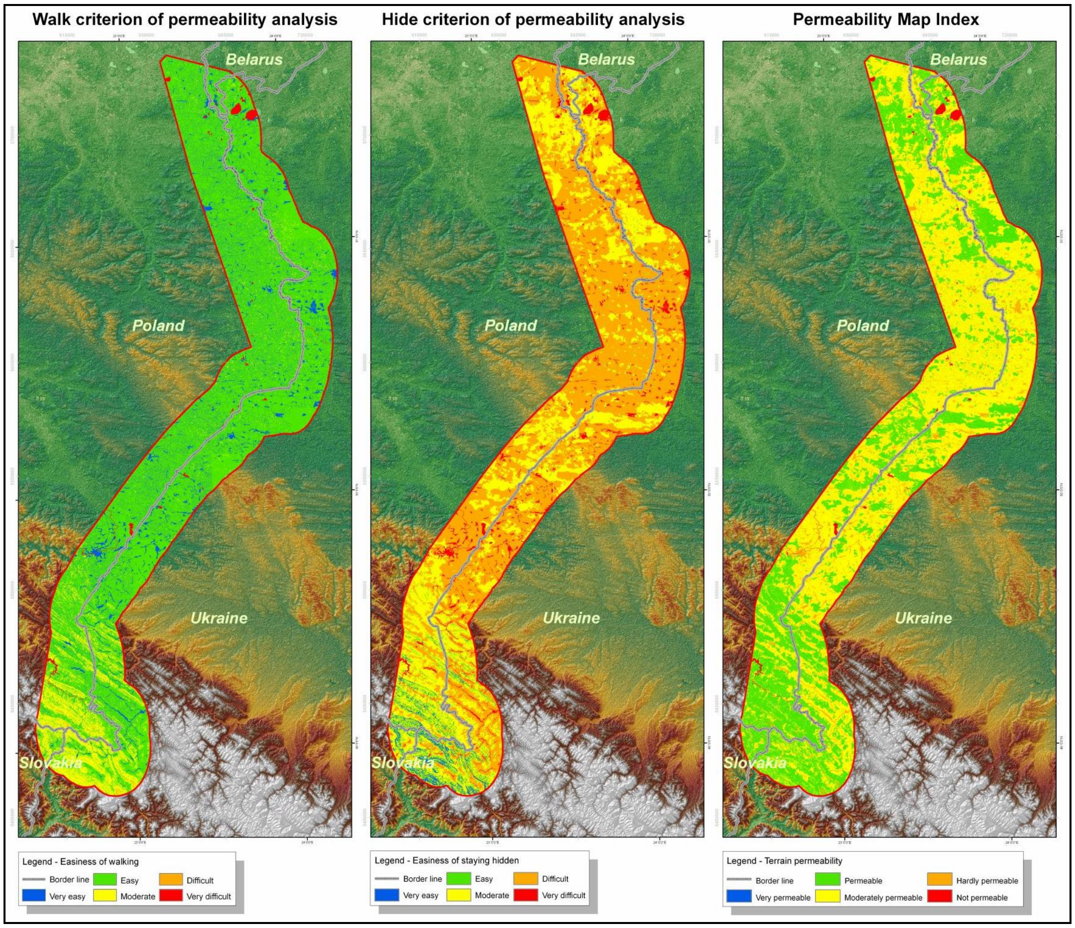


Figure 3. The final results of Border Permeability Index analysis.

The visual comparison of output layers allows to observe that there are some areas inaccessible for walking person. These are mainly water bodies which constitute a barrier for walking person for major part of a year. Based on the achieved results it can be stated that on the area of Polish – Ukrainian border there is no 'Very permeable' areas but a big part of it belongs to the class 'Permeable' and this areas should be under special control of appropriate authorities. The biggest 'Permeable' area can be found on the south of the examined area and this is probably because of the fact that it is mountainous and densely forested area.

## 5. DISCUSSION AND CONCLUSIONS

The BPI model was created and used to produce a cartographic layer. During the analysis some problems occurred while processing data, however, an effort was made to achieve as the best possible results. The problems were caused by the characteristics of different sources of spatial data and difference of scale at which it was provided.

The data with the worst accuracy and precision was CLC2006 and for the next analysis it would be desirable to search for more precise source of land cover data. This can be done for example by classification of IRS imagery (or imagery from other sensor, preferably with higher resolution) for whole study area.

The reliability of the index can be also increased by providing information about the snow cover as the snow has a direct influence on the easiness of walking. A severe winter with heavy frost and huge fall of snow can to a high degree change the walking condition in different terrain. Both the snow cover estimation and snow depth would provide very important indicators for BPI analysis.

An important aspect here was the problem with validation process of the model. For that kind of analysis there is no reference data according to which the result can be compared. Also because of the fact of different scale of the analysis it was impossible to validate the new model with the result of previous analysis. The value of the product can be rather defined in the future after utilization and implementation of the BPI model in practice.

The BPI analysis proved the usefulness of the EO technology for the purpose of land border monitoring. Although it cannot be directly implemented, it still can be used indirectly by implementation of EO data derivations as a source of information for varies spatial analyses.

Regarding to the results achieved in this research it also needs to be admitted that data with higher precision allows to provide more detailed product. Thanks to that fact more useful information can support work of intelligence and end users from spatial domain.

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